Failure Analysis, benefits, logistics, and limitations

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"Vision without action is a daydream. Action without vision is a nightmare."
– Japanese proverb
Failure Analysis

• An important step in product improvement.
• Finding the Root Cause of the problem allows us to eliminate the cause for equipment failure.
Examples

• Fans – bearing changes or grease variations
• Power Supplies – component changes
• ASICs – marginal speed
• Capacitors – process variations
• Cracking parallel to the electrodes is due to stackup or sintering processes during capacitor manufacturing
• These defects can not be detected using ICT or functional test
  – Requires scanning acoustic microscopy (SAM)
• With poor adhesion, maximum stress shifts away from the termination to the defect site
  – No correlation between failure rate and cooling rates (0.5 to 15C/sec)
Failure Characteristics

- Cause
- Mode
- Mechanism
Failure Mode

- Manner or state in which an item or a component might fail. This is what is observed or reported as failure:
  - Low or none output signal,
  - Distorted output,
  - Packs of data missing,
  - Solder interconnect fracture,
  - FET saturation and overheat,
  - Short capacitor, open resistor, etc.
Failure Mechanism

• The physical, chemical, or other process which led to the failure. This is the physical phenomenon that controls the failure
  – Voltage breakdown between conductive tracks,
  – Electromigration, Corrosion,
  – Metal Fatigue, Fracture,
  – Excessive delay or noise, crosstalk,
  – Software looping, division by 0, parity error,
  – Excessive heat, etc.
Failure (Root) Cause

• The circumstances during design, manufacturing, or use environment which have led to failure:
  – Lack of design margin, use of inappropriate technologies, lack of protection against environmental stress.
  – Assembly error, use of defective components.
  – Misuse or abuse of equipment, unpredictable freak events.
When Are Failures Reported?

- During the **Qualification Program**
- **Work In Progress** at the assembly line at **Final Test (End of Line)** and during **Installation**
- **Field Returns**
Qualification Program Failure

- During the product qualification program, environmental stress is used to precipitate and accelerate failures.
- All failures found during qualification program must be analyzed to identify the root cause.
- Design modification must be implemented to correct the problem.
Stress Failure

Threshold Stress Failure (Rupture)

The stress exceeds the threshold strengths of the sample generating material failure. A single event breaks the object.

Cumulative Stress Failure (Fatigue)

The stress applied is below the threshold to failure, but cumulative irreversible damage produced by repeated stress cycles induces material failure.
Qualification Program Failure Challenges

- Most of the qualification programs are capable to induce Threshold Stress Failure.
- Only correctly designed qualification programs can identify Fatigue Failure.
- Qualification program selected must precipitate the same failures as found in the field conditions.
- A proper Acceleration Factor must be determined in order to transfer the information found during qualification program to field conditions.
More Than One Qualification

- Qualify Components
- Qualify Processes
- Qualify Product
Tin Pest (Cold Temperatures)

- Transition of white tin ($\beta$) to grey tin ($\alpha$)
  - Volume increase (~25%)
- Transition temperatures
  - 13.2ºC (thermodynamic)
  - (-10ºC) (initiation)
  - (-30ºC) (max reaction rate)
- Lab results
  - High purity tin
  - Quenched (high residual stresses)
  - Physical contact with grey tin
- Lack of documentation on tin pest in field conditions
Flex Cracks
Flex Crack (examples)
Thermal Shock Cracks

• Due to excessive change in temperature
  – Reflow, cleaning, wave solder, rework
  – Inability of capacitor to relieve stresses during transient conditions.
• Maximum tensile stress occurs near end of termination
  – Determined through transient thermal analyses
  – Model results validated through sectioning of ceramic capacitors exposed to thermal shock conditions
• Three manifestations
  – Visually detectable (rare)
  – Electrically detectable
  – Microcrack (worst-case)
Creep Corrosion

- Will creep corrosion be an issue?
  - Not likely

- Round robin conducted by TI
  - Creep corrosion over the package only observed in Class III MFG environments (moderate industrial)
  - Strong indications of control issues during testing
    - Chloride, humidity

- Recent work confirms environment as the only known driver
  - Blame the janitor
Tin Whiskers

- Current state of knowledge is limited
- Uncertainty on root-cause
- Uncertainty on accelerating growth
- Uncertainty on influence of controllable variables (plating chemistry, contaminants, etc.)
  - NIST claims presence of Cu increases tin whiskering
  - Large OEMs respond through rewriting of specifications
  - Plating supplier demonstrates retardation of whiskering through addition of Cu
Field Failures Analysis

• Performed on parts or equipment recovered from the field after failure.
• Requires a good process for recovering the parts and data associated to the conditions in which the failure was observed.
• Requires cooperation and coordination between the customer, assembly house, part suppliers, design engineering.
• Requires the existence, easy access and manipulation of a complex data base.
Field Failure; Prediction Models

- ARRHENIUS MODEL OF BEHAVIOUR
Device failure under static electro-thermal conditions

- $E_a=1.1 \text{ eV}$
- $E_a=0.8 \text{ eV}$
- $E_a=0.6 \text{ eV}$

Assumption: The device was tested for 10,000 hours at 170°C and the survival rate was higher than 99.9%
Field Failure vs. Use Temperature
Field Failure Data vs. Prediction

Device failure rate (relative scale)

Predicted range

Actual field return range
Field Failure Return Data

• NEW PRODUCTS
  • Failure distributions

Optical equipment

- No data
- No fault found (NFF)
- Device
- Cooler
- Mechanical

Power converters

- Mechanical
- Switches/relays
- Caps resistors
- Devices
- Modification
# Field Failure Summary

## NEW PRODUCTS

<table>
<thead>
<tr>
<th>Failures</th>
<th>Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>LBO switches</td>
<td>Poor device choice</td>
</tr>
<tr>
<td>Membranes</td>
<td>Poor technology choice, poor design compounded by poor supplier process</td>
</tr>
<tr>
<td>NPN transistors</td>
<td>Poor supplier process control and poor technology choice</td>
</tr>
<tr>
<td>Interface devices</td>
<td>Poor design</td>
</tr>
<tr>
<td>RF power amplifier</td>
<td>Totally derailed design process</td>
</tr>
<tr>
<td>ECL ASICs</td>
<td>Marginal design</td>
</tr>
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</table>
Field Return Data

- NEW PRODUCTS
  - ICs involved in less than 40% return incidents
  - Mechanical failure the most common incident
  - 70% of failures concentrated in one or two devices
  - 90% of failures are related to same failure mechanism
  - Design Errors and not Temperature is the leading cause for failure
Mature Design/Technology & Mild Environment
Field Failure Data Shows

- FOR MATURE DESIGN & TECHNOLOGIES,
  - Latent reliability defects are the prime cause of failure
  - Temperature is only one of the acceleration factors
  - Most common environmentally related failure is mechanical failure of the semiconductor interconnect
  - Improvements of reliability can be achieved by improving the parts and assembly quality
Failure Analysis

Challenges, Limitations, Alternatives
End Of Line Verification & FA

- Receive Parts
- Assembly
- Assembly Verification
  - Pass
  - Fail
- Fails in Field
- Fielded
- Repaired
- Failure Analysis
- Root Cause
- Corrective Action
End Of Line Verification & FA

- Little benefit from FA results as the defective lot is already assembled at the time the results are in.
- High cost for absorbing yield loss due to defective parts assembled,
- High cost associated to field failure associated to final test escapes
- FA does not produce a significant value added, as many parts seems to fail in overstress, meaning a different part or something else is the root cause
- Many parts sent to FA show no sign of failure.
Failure Analysis of Replaced Parts

1. Board FA, Identify Part Failed
2. Replace Part, Send Part to FA
3. Perform FA on part, Identify Failure Mode

   - Identify Root Cause
   - Propose Corrective Action
   - Implement Correction Action
Failure Analysis of Replaced Parts

• Very costly as many replaced parts are functional,
• Very slow, normal cycle longer than 6 months,
• Requires specialized test equipment and personnel, not easily available at the CM site,
• Produces questionable results, as the parts failed might not be the root cause of the problem.
• Soft failure due to parametric mismatch between different parts of the assembly or lack of design margin are hard to find and analyze.
Vendor FA examples

- Electrolytic Capacitor formulas
  - Trust us nothing has changed that will concern you
- Ceramic Capacitors
  - The change in factory did not affect the product
- Red Phosphorous flame retardant
  - The mistake was made by one of our vendors
- ENIG board finish on sub assembly
  - “You’re the only one with this issue”
End Of Line Verification & FA

- End of Line Verification and FA cannot be the answer to quality improvement as the process is far too long, difficult to implement, produces unreliable results and it is far too costly.
- By the time the results are in, the faulty equipment carrying defective parts was already assembled and sent to the customer.
- By the time the cause of the problem is identified, most probably the problem was corrected by the designer or supplier.
Solutions

• Design For Reliability Process
  – Technology Selection/Design Margin
  – Component/Supplier Qualification
  – Manufacturing/Assembly Line Qualification
  – Ongoing Reliability Programs
    • Component Quality
    • Assembly Quality
  – Field Follow-up Failure Analysis Program
FA Process Optimization

• Faze 1: Create a data base that shows correlation between field failure modes, component malfunction, and most probable cause(s) for the device malfunction.
• Faze 2: Create a failure reporting system that can associate the field failure to the manufacturing date and field use conditions.
• Faze 3: Create a data base that can correlate WIP test results to probability of field failure
Relationship Between Field and Work In Progress Failures

- Field failures are generated by escapes during the WIP testing due to:
  - Test limitations and errors
  - Marginal product that passes the test but fail in the field after a short period of use (infant mortality).
- Field failures and WIP failures have similar root causes.
- Significant Field Quality Improvements can be made if the root causes that generated WIP failures are eliminated.
- For mature design & technology products, defective parts are the leading factor in generating field failure.
Outgoing Inspection

• Not always enough because:
  – Problems regarding final testing and inspection at the supplier site,
  – The supplier is not aware of the application requirements, it might not test for parameters important for the application,
  – The part specification allows for wider variations of certain parameters than the actual design might allow,
  – The qualification test might not cover for the environmental condition of the application,
  – Manufacturing line might produce marginally “good” parts that are not verified for field degradation.
Outgoing Inspection Problems

- Control Charts
- Performance only measurements
- Just who reads these vendor reports, anyway?
Incoming Inspection
Technical Aspects Problems

• Large varieties of parts with very different characteristics and parameters, with multiple sources and origins.
• Parts require very expensive specialized equipment for proper measurements.
• Parts require specialized set-up and assembly before testing.
• It requires highly specialized and qualified personnel to perform the test.
• It requires data analysis in order to establish if the lot passed or failed.
100% Incoming Inspection

- Not economic, practically impossible considering the resources required.

- **Solution: Lot Acceptance Test**
  - Uses statistical methods to evaluate the probability of having “bad” parts in the delivered lot.
  - Negotiate with the supplier regarding selection of the lots with the best probability of producing high yield,
  - Design & implement test procedures to select the best lots for the application.
Why Lot Inspection Test?

- Necessary to verify supplier outgoing inspection
  - To eliminate the possibility of receiving bad parts due to process, procedure, and inspection errors at supplier
- Most efficient method to verify supplier quality
  - Compared with,
    - Test after Assembly (End of Line) + Failure Analysis
    - 100% Incoming Inspection
    - Onsite Test Auditor
- Necessary to ensure the predictability of the assembly quality
  - Yield prediction
  - Design margin verification
Why Lot Inspection Test Works?

• When causes that can produce defective parts in a qualified & stable manufacturing environment are analyzed, one can conclude that defective parts are related to temporary variations of the materials and processes involved in producing the part.

• The defective parts are not randomly distributed through the entire parts population, but concentrated in a small number of lots that were manufactured during the brief periods the process was not under control.

• Identification and screening of the defective lots would reduce the number of defective parts received to an acceptable minimum.
Process Characterization
Logistics Problems

- The incoming inspection can be provided by:
  - Contract Manufacturer
  - Company
  - A Third Party
Process Characterization
Logistics Problems

- Incoming Inspection/LAT performed by CM
  - Very unlikely the CM has or it is capable to provide the test equipment required.
  - Very unlikely the CM has the personnel required to design the tests, assembly the set-ups, perform the tests, and interpret the results.
  - CM must charge Company for all of these expenses.
  - CONFLICT OF INTEREST, as the CM benefits from the assembly of bad parts.
Process Characterization
Logistics Problems

• Incoming Inspection/LAT performed by a Third Party:
  – No conflict of interest, easier to mitigate conflicts created by disputed results.
  – Can allocate personnel in a far more efficient way.
  – Can use equipment and facilities that already exist at the supplier site or at test houses.
  – Has more flexibility in finding and allocating resources as required.